# SOME RECENT DEVELOPMENTS OF BASIC SIGNIFICANCE FOR PHOTO INTERPRETATION

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# SOME RECENT DEVELOPMENTS OF BASIC SIGNIFICANCE FOR PHOTO INTERPRETATION*

by

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Several of the papers presented at this conference have recounted significant progress being made in photo interpretation as applied to a specific field such as forestry, geology, agriculture or urban planning. The purpose of this paper is to summarize recent developments which, because of their very basic nature, are applicable to all of these fields of photo interpretation, and to many others as well. Although some of the material presented here may overlap that presented in other papers, it is believed that the fresh approach may justify the small amount of duplication.

The "fresh approach" attempted in this paper is mainly an organizational one. It has been arrived at through consideration of the following facts which are as basic to photo interpretation as they are obvious: If aerial photographic interpretation in any of its applied forms is to be employed successfully, four conditions must be satisfied: (1) The aerial photography must provide images of suitable quality for extracting the type of information that is to be obtained through photo interpretation; (2) the men performing this photo interpretation work must have been properly selected and trained; (3) the equipment used in viewing, measuring and interpreting the photographic images must be of suitable quality; and (4) the methods and techniques used by the photo interpreter must permit him to extract the desired information both efficiently and accurately.

The remainder of this paper attempts to recount recent developments within each of the four categories suggested by the above statement.

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## I. RECENT IMPROVEMENTS IN PHOTOGRAPHIC IMAGE QUALITY

This type of progress is best reported in terms of the major factors contributing to photographic image quality. According to one viewpoint (Colwell, 1954) there are three such factors: (1) the photographic tone or color contrast between an object and its background; (2) the sharpness characteristics of the photographic image; and (3) the stereoscopic parallax characteristics. Without our having a clear understanding of these terms, it would be fruitless to describe recent progress relative to them. Figure 1 serves to illustrate the meaning of each of these three terms as applied to the images of a tree, as seen on a stereoscopic pair of aerial photos. A tree has been selected for this illustration, not only because it is the basic unit of interest to those making forest inventories from aerial photos, (as reported in some of the other papers), but also because it is illustrative of many other three-dimensional objects in which photo interpreters are interested.

By photographic <u>tone contrast</u> is meant the difference in brightness between an image and its background. Thus, in the black-and-white photography of Figure 1, tone contrast is exemplified by the difference in brightness between points A and B of the photograph. Similarly, in color photography, the term "color contrast" pertains to the resultant of all the hue, value and chroma differences between an image and its background. If there were appreciably less tone contrasts on the photos at the top of Figure 1, the tree images would blend with the background and would be imperceptible.

By <u>sharpness</u> is meant the abruptness with which the tone or color contrast appears to take place on the photograph. Thus, in Figure 1, sharpness is indicated by the distance on the photograph over which the change from Tone "A" to Tone "B" appears to take place. If there were appreciably less sharpness on the photos at the top of Figure 1, the tree images would be merely unidentifiable blobs.

Often, in times past, photo interpreters have considered that the only means by which they could see finer details on photographs was by obtaining photographs of larger scale. The relation of sharpness to photographic scale is apparent when we consider the resolution, or resolving power, of photography in terms of discernible lines per millimeter. The sharper the photography, the more lines per millimeter are discernible and the finer is the discernible detail. Thus, if a certain number of lines per <u>object</u> are required in order to be sure that a certain blob is a tree, this number of lines can be obtained by either (a) increasing the photographic sharpness (in lines per millimeter) at a given scale,

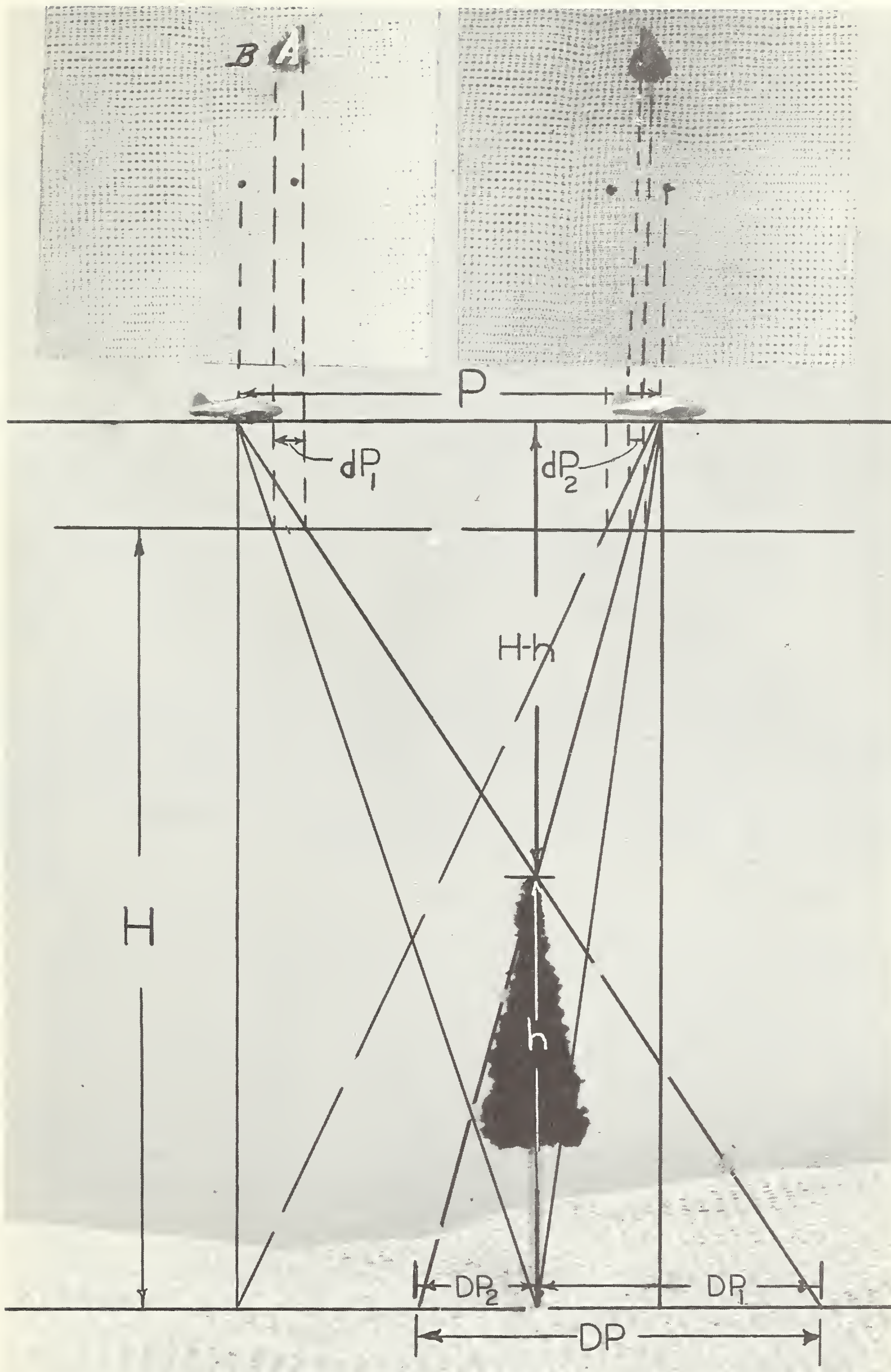


FIGURE 1
**Three-dimensional model of a tree, constructed for the purpose of illustrating the terms tone contrast, sharpness, and stereoscopic parallax, as discussed in the text.**

or (b) increasing the photographic scale at a given sharpness. Since the cost of aerial photography, as well as much of the work done with it, increases roughly as the square of the scale, it often is more fruitful to consider means of increasing photographic sharpness, rather than photographic scale, when the objective is to see more detail on the photographs. Progress in this aspect of image quality will be cited presently.

Stereoscopic parallax is the displacement of the apparent position of a body with respect to a reference point or system caused by a shift in the point of observation. Thus, in Figure 1, if camera stations 1 and 2 (indicated by the two positions of the aircraft) are the two points of observation, the stereoscopic parallax of the top of the tree with respect to its base is the ground distance, DP. The photo equivalent of DP is dP (the arithmetical sum of $dP_1$ and $dP_2$), which is the shift in the apparent position of the top of the tree with respect to its base as seen on the stereoscopic pair of photographs. If this shift is too slight it will not be clearly perceptible when two overlapping photos are viewed stereoscopically; consequently tree height, a factor of great importance to the forest inventory expert, will not be clearly perceived on such photography. Likewise, if this shift is too great, it again will not be clearly perceptible when two overlapping photos are viewed stereoscopically. This is because of inability of the human eyes to fuse simultaneously two sets of images (one set for the top of the tree, the other for the base of the tree), when the sets require vastly different amounts of convergence of the observer's two lines of sight. Consequently the requirement is to obtain optimum, rather than maximum stereoscopic parallax in aerial photography.

## A. IMPROVEMENT IN THE TONE OR COLOR CONTRAST CHARACTERISTICS.

Recent improvements in this aspect of photo image quality become apparent when we consider that there are four main factors contributing to the tone or color contrast characteristics of images as seen on aerial photographs. These are (1) the spectral reflectivity of light from an object and from its background; (2) spectral sensitivity of the photographic film, (3) spectral transmission of the photographic filter; and (4) spectral scattering by atmospheric haze particles. In terms of these factors the following progress has recently been made:

A greatly improved instrument for measuring the spectral reflectivity of light from an object and from its background has been developed. This is the portable spectrophotometer shown in Figure 2 which permits spectral measurements to be made of sizable "in-place" samples.

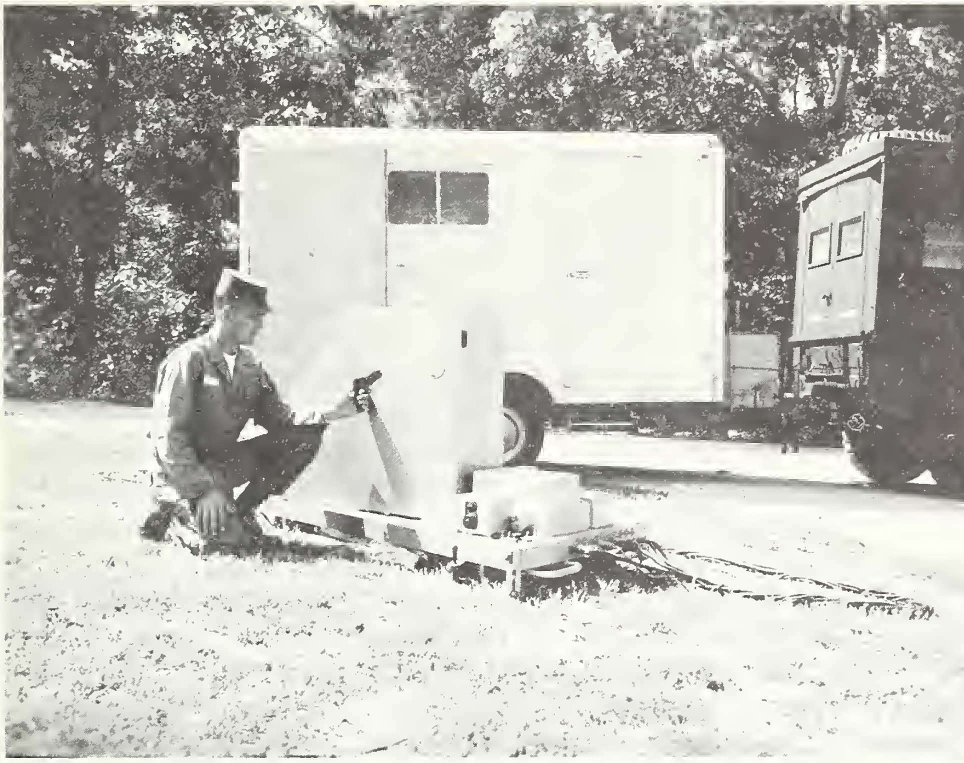

FIGURE 2
Recently-developed portable spectrophotometer for use in making spectral reflectance measurements in the field when samples cannot be brought to the laboratory for analysis without distorting their reflectance characteristics. (Photo courtesy of Engineer Research and Development Laboratories, U. S. Army Corps of Engineers, Fort Belvoir, Virginia). For full discussion of the value of this instrument, see article by Dwornik and Orr (1961).

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(Dwornik and Orr, 1961). Previously each sample had to be collected, mounted between two glass plates and placed in front of the small circular window of a laboratory-type spectrophotometer. The smallness of the sample analyzed, and the disrupted nature of the sample itself, often resulted in erroneous values being obtained for the spectral reflectivity of objects. Consequently serious errors resulted, when attempting to select the best combination of photographic film and filter for use in making desired distinctions by virtue of photographic tone or color contrasts.

Even when accurate spectrophotometric data are available, there is need for rigorous mathematical analyses of the data to determine which part of the spectrum will provide optimum tone or color contrasts between an object and its background. According to Langley (1961) the computations required to determine, statistically, where this optimum contrast will be found are so involved as to necessitate

the use of an electronic computing machine. He appears to be the first to have devised a satisfactory method of programming the raw data so that correct answers will be provided by the computing machine.

A very versatile color film has been made available for aerial use, at a cost only moderately greater than that of conventional black-and-white film. Known as "Aerial Ektacolor", this film produces a color negative of excellent quality from which positive color prints or transparencies as well as positive black-and-white prints or transparencies can be made. The black-and-white prints, when made on a special Eastman Kodak paper known as "Pan Allure", are of fully as good quality as those printable from conventional aerial panchromatic films. Of perhaps greater significance, photo interpreters have already found that opaque color prints made from these same negatives on a color-sensitized paper known as "Printon" greatly facilitate the photo mapping of soil boundaries (Dominguez, 1960), the photo identification and height measurement of trees (Veruette, 1961), and the photo interpretation of rock types and determination of their orientations and distributions (Fischer, 1958). The color prints are essentially as adaptable to field use as are black-and-white prints and are prepared at only moderately greater cost, from the color negatives. The color transparencies are even more interpretable than the color prints, but ordinarily must be viewed in the laboratory over a light table.

Another color film, known as "Camouflage Detection Film", although developed nearly twenty years ago, has recently been found to be very valuable as a means of differentiating at an early date between healthy and unhealthy vegatation (American Society of Photogrammetry, 1960). Such distinctions are made only with great difficulty, if at all, on conventional black-and-white or color photography at this early date.

Technological improvements in the construction of narrow-band-pass filters have made it feasible, for the first time, to exploit tone or color contrasts between an object and its background. Without this development many of the findings available through use of improved spectrophotometers and electronic computers, as previously discussed, would remain unexploitable by the photo interpreter. (Langley,1961)

Greater appreciation of the selective scattering of spectral energy by atmospheric haze particles has resulted in better

photo image quality being obtained, particularly on low altitude, large scale photography where the objective is to discern the maximum of detail in shaded areas. In one recent experiment of this type, (Colwell and Marcus, 1961) the objective was to develop a means of estimating the intensity of recreational use in wildland areas by means of aerial photography. Consistent with Rayleigh's Law, which states that the scattering of light is inversely proportional to the fourth power of the wavelength of the light, these investigators found that far more detail was discernible in shaded areas when the photographs were taken with short wavelengths of light, (380 to 450 millimicrons). This is because only the scattered light illuminates shaded areas, including those in which recreationists most frequently will be found as they occupy the campgrounds of wildland areas, consequently the short wavelengths, being scattered most, are capable of providing the best detail in shaded areas on large scale low altitude photography. This finding is also of significance to the timber inventory expert who wishes to determine the kind and amount of vegetation in the forest understory, or who wishes to measure the heights of trees in dense stands where the forest floor is in heavy shade.

B. IMPROVEMENT IN SHARPNESS CHARACTERISTICS.

The main factors governing the sharpness of photographic images are (1) aberrations of the lens system; (2) focus of the lens system; (3) image motions at the instant of exposure; and (4) characteristics of the photographic materials.

Recent development of the Infragon lens has eliminated most of the lens aberration problems that until recently were experienced when aerial photographers attempted to obtain acceptably sharp infrared photography through the use of conventional aerial camera lenses. Since conventional lenses have been color-corrected at the time of manufacture on the assumption that only panchromatic minus-blue photography would be taken with them, it is not surprising that they give poor image sharpness characteristics when used to take infrared photography.

Improper focus of the lens system has, until recently, been an additional factor limiting the sharpness of infrared aerial photographic images. This results from the fact that until recently infrared photography usually was taken merely by placing infrared-sensitive film in a conventional

aerial camera. On such a camera the distance from camera lens to focal plane usually has been accurately fixed, on the assumption that only panchromatic minus-blue photography will be taken with it. Since the wavelengths used in taking infrared aerial photography are brought to focus at a distance which is about 2% greater than this normal focal setting, modern cameras used in taking infrared photography have this improved focus feature as well as the improved lens characteristics previously mentioned. The infrared aerial photography obtained with the improved equipment is considerably sharper than that obtained heretofore.

Image motions at the instant of exposure no longer need be of such magnitude as to detract seriously from the sharpness of aerial photographic images, because of progress in the development of two devices. One of these minimizes the amount of vibration of the camera at the instant of photography; the other, known as an "image-motion-compensation" device, compensates for the travel of images at the focal plane during the instant of photography. It is becoming increasingly common to require that aerial photography, when flown even from altitudes of 15,000 feet or more, be taken only with cameras equipped with an image-motion-compensation device. The purpose of this requirement is to ensure that the sharpest possible photographic imagery will be obtained.

Among the various characteristics of photographic materials which appreciably affect the sharpness of photographic images, perhaps the most significant is that of film graininess. The dilemma that has previously confronted photo interpreters wishing to draft specifications for aerial photography was as follows: (1) If a fast film were used, it proved to be too grainy, with consequent loss of image sharpness; conversely, (2) if a very fine-grained film were used, it proved to be too slow, and sharpness was again lost, in this instance due to the aforementioned vibrations and other motions taking place during the prolonged instant of exposure. Recently, however, film manufacturers have made great strides in developing black-and-white aerial photographic films (including Eastman Kodak's "SO 213" and "SO 243" films) which are both acceptably fast (particularly in view of recent improvements in minimizing image motion) and unusually fine grained. (Tarkington, 1959). Similar progress also has been made with aerial color films.

## C. IMPROVEMENT IN STEREOSCOPIC PARALLAX CHARACTERISTICS.

From an examination of Figure 1 it is apparent that the magnitude of stereoscopic parallax (dP) in a pair of overlapping aerial photographs is directly proportional to the length of the air base, P; directly proportional to the height of the object, h; and inversely proportional to the altitude of photography, H.

In times past, those interested in making maximum use of aerial photographs in forest inventory, for example, have made several unsuccessful attempts to use very large scale stereoscopic pairs of photos for the measurement of individual tree volumes on selected sample plots. Lack of success usually was attributable to the fact that the air base, P, was too large in relation to the tree height, h, and also somewhat too variable. Both difficulties have recently been overcome by simultaneous use of two cameras operating from opposite ends of a short boom mounted on a helicopter, (Avery, 1958; Lyons, 1960a, b). This ingenious device should also permit the geologist, agriculturist and many others to study small selected spots of interest on large scale aerial photography having a suitably small amount of stereoscopic parallax to permit detailed interpretation.

There has also been a need in times past for obtaining a greater amount of stereoscopic parallax on photography flown at a scale of 1/20,000 or smaller. Only by increasing the parallax could photo measurements of tree and stand heights, for example, be made to a usable order of accuracy on photography of such small scale. Recent experimentation with "convergent photography" indicates that the greatly increased stereo base offered by such photography usually provides a sufficient increase in the stereoscopic parallax to offer a workable solution to this difficulty.

# II. RECENT IMPROVEMENTS IN THE SELECTION AND TRAINING OF PHOTO INTERPRETERS

Until recently there was a tendency to assume that one person was as well suited to photo interpretation work as another. Consequently the selection process revolved primarily around considerations as to the relative availability of two or more people to handle an additional task, in this instance aerial photographic interpretation. However, we are gradually coming to realize that the differences between a good photo interpreter and a poor one can be largely explained on the basis of (1) differences in visual acuity, (2) differences in mental acuity, and (3) differences in general attitude

toward the photo interpretation task. Therefore, progress in this aspect is logically discussed under headings suggested by the above three factors.

A. IMPROVED TESTING OF THE CANDIDATE'S VISUAL ACUITY.

The stereoscopic test developed by Moessner (1954) has proved to be immensely popular among photo interpreters, despite certain admitted inadequacies of the test. As indicated by our earlier discussion, however, stereoscopic parallax is only one of three primary photo image characteristics on which most kinds of photo interpretation are based.

Figure 3 shows a somewhat more complete visual test chart (Colwell, 1959). It is a stereoscopic pair of actual vertical photographs of a three-dimensional resolution target. It is so designed as to permit the testing of a candidate's ability to perceive tone contrast and sharpness as well as stereoscopic parallax. Furthermore these parameters can be tested in any desired combination, a factor of some importance since they typically are found in all possible combinations on actual aerial photographs.

The U. S. Naval Photographic Interpretation Center is currently preparing a three-dimensional test chart of a similar nature. It is possible that such visual acuity test charts will be used quite extensively in the future in the selection and training of candidates for photo interpretation work. The U. S. Navy is also supporting a study of factors affecting vision in photographic interpretation by Dr. Lund and associates at Tufts University. In addition, Rabben (1955, 1960) has written two excellent articles on the visual factors in photo interpretation. These articles have done much to increase our awareness of the importance of visual acuity tests in determining the suitability of candidates for performing photo interpretation tasks.

B. IMPROVED TESTING OF THE CANDIDATE'S MENTAL ACUITY.

Dr. E. Lawrence Chalmers, Jr., and his associates at the U. S. Air Force Personnel and Training Research Center recently devised a series of tests for use in the selection of photo interpretation trainees. Performance in most of these tests has been found to be closely related to

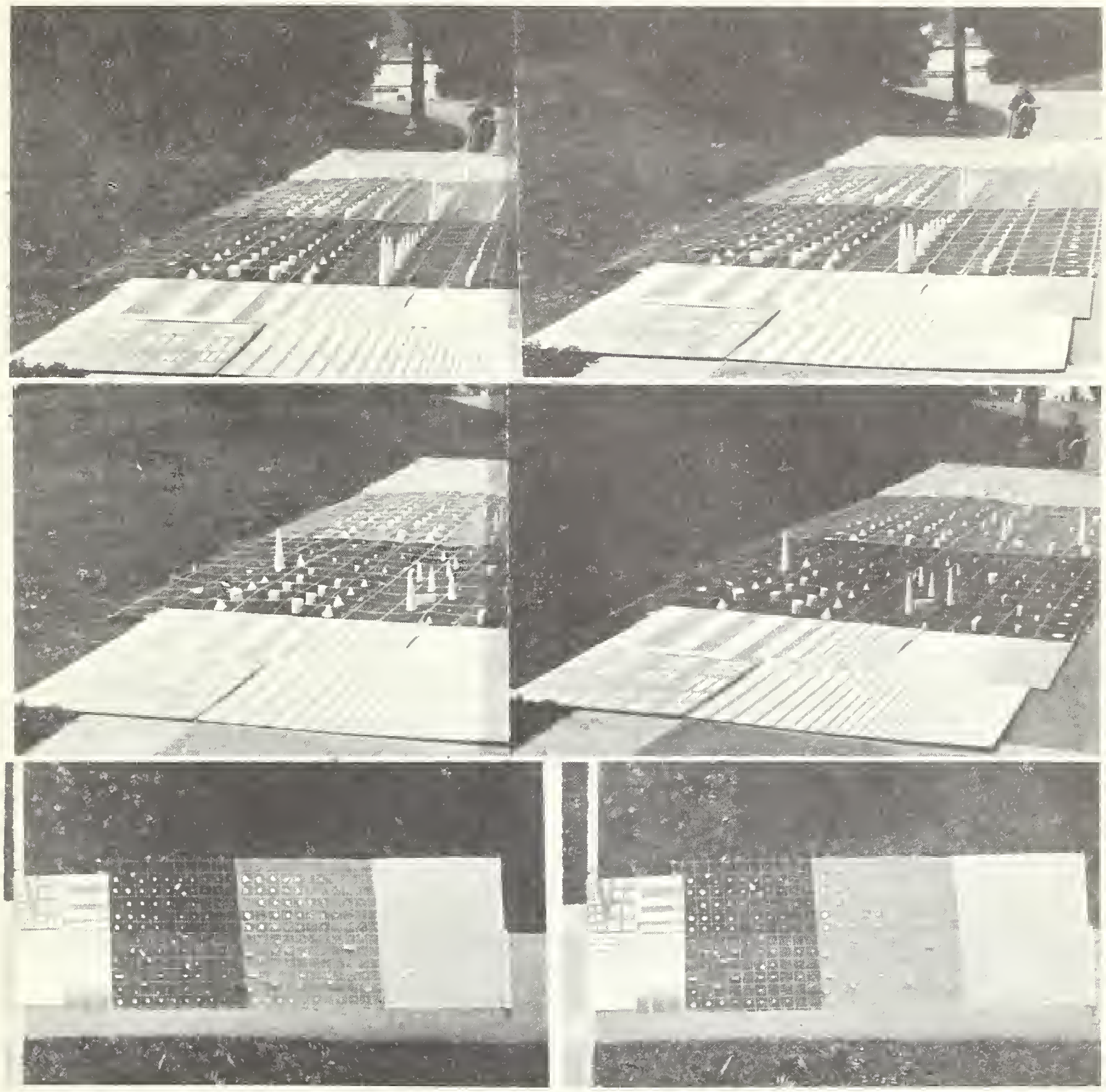

FIGURE 3

A composite resolution target suitable for (1) measuring the tone contrast, sharpness, and stereoscopic parallax characteristics of aerial photography, (2) testing the detectability and recognizability of objects as a function of these three parameters, (3) testing the visual acuity of photo interpreters under varying degrees of fatigue in terms of these same three parameters, and (4) testing the clarity with which these three parameters can be perceived with various types of viewing equipment used by the photo interpreter. Top photo is a stereo ground view of the target in which various three dimensional objects and their two dimensional counterparts have been placed in orderly array against dark, medium and light-toned backgrounds. In left foreground is a standard Air Force resolution target; in right foreground is a sinusoidal type of resolution target consisting of long, dark-toned bars on a light background; behind these two panels are a grey scale and a second bar-type resolution target in which transition from dark tone to light is abrupt rather than sinusoidal. Middle photo is of same target, but the objects have been arranged in one of several random positions to better test the threshholds of detectability and recognizability. Bottom photo is a vertical stereogram of same target with objects randomly arranged. It is on such vertical stereograms as this that the testing is done.

performance in photo interpretation. The tests which Chalmers used are summarized in Table 1.

Table 1

A Proposed Aptitude Test For

Photograph Users

1. Spatial Orientation. (Subject must find the part of an aerial photograph that is identical to a small cutout)

2. Aerial Landmarks. (Objects imaged in vertical photography must be detected in oblique photography)

3. Plotting Flexibility. (Subject moves in certain directions according to codes)

4. Estimation of Length. (Subject matches the length of a line to one of a series of variable standards)

5. Object Completion. (Subject identifies objects from incomplete visual representation)

6. Closure. (Subject locates hidden faces and geometric figures and recognizes incomplete words)

7. Picture Integration. (Subject rearranges four quadrants of a single photograph)

8. Figure Analogies. (Subject reasons, using visual figures)

9. Position Orientation. (Subject recognizes right-and-left hand objects from drawings of the objects in a variety of positions)

10. Shadow Identification. (Subject identifies geometric figures from the shadows they cast)

11. Logical Reasoning. (Subject judges correctness of conclusions drawn from general statements)

In additional tests Chalmers found highly significant correlations between the candidate's photo interpretation abilities and his abilities in General Mathematics, Mechanical Principles and Arithmetic Reasoning; somewhat lower correlations were found with respect to Aerial Orientation, Visualization of Maneuvers, and Ability in the General Sciences. Chalmers states (American Society of Photogrammetry, 1960) that other factors which ought to be considered in selection procedures are the interpreter's capacity for learning, adaptability, and powers of judgment. The interpreter who cannot readily acquire and retain information is evidently a poor risk. The successful interpreter can change pace, concentrate in difficult circumstances and make intelligent use of his knowledge. As Chalmers points out these abilities are very difficult to evaluate in testing, however.

Personnel at the Forestry and Timber Bureau in Canberra, Australia, have devised tests to be used in the selection of the most suitable personnel for training in photo interpretation. (Sims and Hall, 1956) One of these, a "photo reading" test, involves the direct recognition, through stereoscopic examination of aerial photos, of various natural and artificial objects with which the candidate ordinarily would have some familiarity from ground observation. Examples are a bridge, dam, wharf, church, lighthouse and railroad turntable. Another, known as a "photo interpretation" test, involves the ability to deduce or "interpret", from features which can be readily recognized, the meaning of other features or objects which usually cannot, by direct study of their images, be readily identified. Examples are a bus depot, an electric power station, a sewage plant, and a rifle range. In other tests the candidates are given small portions of aerial photos and are asked to locate the corresponding portions of the terrain on aerial photos or maps which are usually of a different scale than the small photos. All of these tests correlate well with the candidate's eventual performance as a photo interpreter. In terms of overall mental acuity, these investigators recommend that the candidate have an intelligence quotient of 120 or higher.

Similar work is currently being undertaken by personnel of the U. S. Army's Personnel Research Branch of the Adjutant General's Office under the title "Human Factors Studies on Image Interpretation." Some of the first results of this work are soon to be published by Martinek, Ranes, Schwartz, and Castelnovo (1961).

## C. TESTS OF THE CANDIDATE'S ATTITUDE TOWARD THE PHOTO INTERPRETATION TASK.

It is encouraging to see that at least a limited amount of attention finally has been given to this important human factor. Rabben (1960) states:

> "Often the supervisor is aware only dimly or not at all of his subordinates' undesirable attitudes and poor motivation, and of the extent to which these factors interfere with efficient performance. Suppose, for example, that an aerial photograph images an object x which is important for a particular type of photo interpretation. Many human factors determine whether or not a given interpreter will report object x. Assume that object x was not reported and the interpreter is then asked 'What about this object?' (while pointing to object x). If the response is 'That's object x. I didn't see it. I should report it,' it may be inferred that the interpreter failed to find x in the photograph, either because he was careless or tired, or because the image was too small or otherwise obscure to attract his attention... If the response is 'That's object x, I saw it. I didn't think it should be reported,' we infer that the importance of x is not known to the interpreter. If the response is 'That's object x. I saw it. I know it's important. I didn't bother to report it,' we infer a lack of interest in the job or a lack of motivation. If the response is 'I didn't know what that object was when I saw it,' we infer that knowledge of object x is deficient. These brief and oversimplified examples only begin to uncover the human factors at play in the activities of photo-object identification."

Chalmers states that the Air Force's previously-mentioned research program included a measure of motivation. (American Society of Photogrammetry, 1960) It consisted of a number of statements about students' behavior, e.g., "sleeps in class," "does outside reading," "volunteers information in class." Two or more instructors were asked whether the statement applied to each student always, often, frequently, seldom, or never. The scores on this measure were highly related to most measures of photo interpretation

performance. The student who never slept in class, always did outside work, and frequently volunteered information in class, was most likely to detect and identify images in photography.

### D. IMPROVEMENTS IN PHOTO INTERPRETATION TRAINING METHODS AND MATERIALS.

Once the photo interpretation candidate has been selected there still remains an important requirement to train him properly to do photo interpretation work. Significant progress also has recently been made in this important aspect of the problem.

The Intermountain Forest and Range Experiment Station of the U. S. Forest Service has recently published a document entitled "Training Handbook, Basic Techniques in Forest Photo Interpretation" (Moessner, 1960). This consists primarily of a series of practical photo interpretation problems involving forest inventory and related aspects of photo interpretation. For each problem, an acceptable solution is given and the basic photo interpretation techniques illustrated by the problem are emphasized. The manual is in such a form as to permit its use either for group study or for self study by those interested in acquiring basic knowledge of photo interpretation.

Cheney (1960) has made a survey of training in photo interpretation presently being conducted in the United States and elsewhere. By pooling the information obtained from 63 instructors, he has done much to summarize meaningful opinions regarding the best way to train students in photo interpretation work.

## III. RECENT IMPROVEMENTS IN PHOTO INTERPRETATION EQUIPMENT

Photo interpreters need equipment for three general purposes: viewing, measuring, and transferring or recording detail. Viewing instruments provide either stereoscopic or two-dimensional views; measuring instruments may be used on single photographs or stereoscopic pairs; and instruments which record or transfer detail do so either through use of the "camera lucida" principle, by projection, or by means of a pantograph.

An excellent, up-to-date summary of each of these types of photo interpretation equipment has been published by Pickup (1960). The summary provides a graphic indication of recent progress in this area. Among the types of <u>viewing equipment</u> which he discusses are

stereoscopic viewing instruments, monocular magnifiers and light tables; among the types of measuring equipment which he discusses are items devised for making linear measurements, those for making height measurements and those for making area measurements from aerial photographs; and among the types of equipment for transferring and recording detail he considers separately those designed for transferring detail from single photographs, and from stereoscopic pairs of photographs. Also discussed are rectifiers, lamps, dividers, plotting templates, slotted template cutters, dot counters, sound recorders, and photo interpreter's slide rules, all of which are assuming increasing importance in many kinds of photo interpretation work. Most of these types of equipment are very well illustrated in Pickup's article.

In the quadrennial report by the President of Commission VII of the International Society of Photogrammetry, Coleman (1960) describes several of the more important new types of instruments being used by photo interpreters, including light tables, rear projection viewers, high magnification equipment, and electronic plotters coupled with analogue or digital computers. He points out that a great amount of the photo interpretation work now being done uses photographic transparencies rather than opaque paper prints. The transparencies are viewed with rear illumination, usually with the aid of a light table. This system has the following advantages: (a) since much of the detail to be interpreted is rendered in dark tones on a positive photograph, the use of rear-lighted transparencies permits better image illumination than is obtained with reflected light on paper prints; (b) the absence of paper grain in film transparencies permits greater magnifications to be used without loss of the image; and (c) the use of connected-roll transparencies avoids the sorting and filing problems inherent in handling separated paper prints.

The increased use of transparencies has led to the development of rear-projection viewers, specifically designed for photo interpretation use. These instruments usually provide for a standard magnification of the image during projection (four, eight, or as high as twenty times). Many of them permit measurements to be made through the reading of rectangular or polar coordinates on devices which traverse the projected image (Coleman, 1960). These measuring devices are easily fitted with magnetic tape for automatic plotting or electronic computation, as explained in a later paragraph. Some rear-projection viewers have a stereo-projection capability.

Careful film processing and the use of transparencies has permitted photo interpreters to employ high-magnification equipment. Among

the more successful devices offering high magnification are microscopes modified for the stereo viewing of photographs. These have varying magnifications, usually starting at about eight diameters, and extending, through the use of turret lenses or the zoom magnification principle, to a magnification of forty diameters or more.

The photo interpreter frequently has the requirement of making a planimetric drawing of his data, either to an arbitrary scale on plain paper or to a specified scale on an existing map. This problem is often facilitated through the use of a digital computer system. The photograph is laid on an x-y coordinatograph, equipped with magnetic read-out heads, so that the successive positions of the courser, as it traces out the detail interpreted from the photograph, are punched into computer tape. According to Coleman (1960), the programmed operation of the computer may be designed to rectify data from oblique photography to the vertical. After the calculations have been completed, the output tape from the computer is fed into a second x-y plotter, which plots the new position of each point.

An analogue system has been devised which works in much the same way except that both plotters are connected directly to an analogue computer without a punched-tape step intervening. The use of an analogue computer permits unrectified line material to be traced in its rectified position in a single, continuous operation.

Bernstein (1960) has reported on a parallax factor alignment chart. From the chart a parallax factor is read as a function of the focal length of the taking camera, altitude of photography and photo base length. This factor then converts parallax differences, as measured on the photographs, to heights or differences in elevation between two points.

Statistical sampling through the use of photo plots constitutes an important aspect of modern inventory methods (Rogers, 1960) (Allison and Breadon, 1960) (Smith, Lee and Dobie, 1960) (Lee, 1960) (Wolff, 1960). Consequently computing machines are also being employed by photo interpreters to make multiple correlation analyses, derive multiple regression equations, and determine the statistical reliability of various sizes of samples and methods of sampling. Such equipment is making possible the employment of photo inventory sampling methods that heretofore could never have been used because of their unknown statistical reliability.

An account of recently-developed aids to photo interpretation must make mention of the "keys" and related reference materials that have recently been published. These keys are designed to facilitate the rapid and accurate identification of various objects and conditions from a study of their photographic images. They commonly consist of two parts, (Colwell, 1952); (a) a collection of annotated or captioned stereograms and other photos which are illustrative of the objects or conditions to be identified; and (b) a graphic or word description which sets forth in some systematic fashion the photo recognition features of those objects or conditions. Recently published examples are the keys and similar aids prepared by Avery, (1960b), Miller, (1960), Moessner, (1949), Wilson, (1960), and Sayn-Wittgenstein, (1960, 1961). A selected, annotated bibliography of aerial photo interpretation keys to forests and other natural vegetation has been prepared by Choate, (1957).

## IV. RECENT IMPROVEMENTS IN THE METHODS AND TECHNIQUES OF PHOTO INTERPRETATION.

Before considering new techniques it would be well to emphasize that much yet needs to be done to master the long-established and highly necessary techniques used in interpreting aerial photographs, including the following:

Methods for orienting a stereo model beneath the stereoscope. The objective should be to accomplish this act quickly, yet in such a way as to permit the most realistic three-dimensional impression to be obtained of the model, while avoiding unnecessary eye strain for the photo interpreter. Although most photo interpreters have long since developed the ability to accomplish this orientation, most of them could greatly improve their ability in this respect if they were to analyze the waste motions and other inefficiencies in their habitual procedures. The recently-developed photo alignment guide (Moessner, 1960) is of genuine assistance in improving this technique.

Methods for handling a large stack of photos in an orderly manner during the photo interpretation process. The advantage of some system for the orderly progression of photos from one position to the next, as a large stack of them is being interpreted, can be very great. The advantage is apparent, however, only when contrasted with the haphazard crossings over and rotations of prints that usually ensue when an interpreter simply plops down a stack of photos and starts interpreting them. A detailed description of one approved procedure appears in the article by Rabben, (1960).

Methods for avoiding duplication or omission in the interpretation of areas common to two or more stereoscopic models. This is of such importance in the interpretation of end lap areas common to two successive photos in a flight line, or of sidelap areas common to two adjacent flight lines as to permit a reduction of from 30 to 50 percent in the photo area which otherwise would be interpreted. The technique required here is that of delineating the "effective area" of each photograph (or of alternate photographs in some situations). The effective area is that portion of a photograph which is imaged more nearly toward the center of the photo in question than it is to the center of any other photograph, either within the line of flight or in adjacent flight lines.

Methods for systematically searching the area encompassed by a stereo model. At present no particular search method can be recommended above all others. Nevertheless, it is important that the photo interpreter settle upon some systematic search pattern to be certain that each area of the stereo model is examined at least once, but not unnecessarily more than once.

Other methods and techniques. One of the most encouraging signs of recent progress in this aspect of photo interpretation is to be found in the Training Plan for Developing Basic Techniques in Forest Photo Interpretation. (Moessner, 1960). It is revealing to enumerate the thirteen problems comprising this training plan, as they constitute a good summary of the more important basic techniques. They are: stereoperception test, positioning photos for best stereovision, recognition of ground cover conditions, determining photo scale, determining project scale and flying height, determining bearing and distance on aerial photos, determining relative elevation by parallax wedge, measurement of tree and stand heights by parallax wedge, estimating crown diameter and crown coverage, estimating board-foot and cubic-foot volume on sample plots, dot sampling for areas, direct volume estimates from aerial photos, measuring slope percents and road planning on photos.

Although it is not within the province of this paper to report in detail relative to each of these many techniques, evidence of significant progress is to be found in the mere fact that the techniques used by a photo interpreter for a specific purpose are being categorized and carefully studied.

## V. A LOOK TO THE FUTURE

In any report that deals primarily with progress recently made, it is only natural to conclude with a report of progress still anticipated. As we attempt to peer into the future we are, perhaps, fortunate that only a hasty summary of anticipated progress can justifiably be included in a paper such as this. For experience has shown us that even photo interpreters with the highest visual acuity can scarcely claim 20/20 vision when peering into the crystal ball to predict the future. The following, therefore, represents only one photo interpreter's terse predictions of types of progress soon to be made in the use of aerial photographs. Consistent with the sequence followed in the preceding portions of this report, the predictions are made for each link in the chain, from the taking of aerial photography to the eventual production of a photo interpretation report.

### A. THE AERIAL PHOTOGRAPHY USED IN THE FUTURE WILL BE OF A FAR MORE DIVERSE NATURE THAN HERETOFORE.

For the first time, extremely small scale photography taken with a photo reconnaissance satellite from an altitude of nearly 200 miles will be available for civil as well as military photo interpretation work. Even though this photography may permit us to do little more than discover and evaluate, in crudest terms, the natural resources in vast and remote areas, it will be of tremendous value in helping to plan for the economic growth of underdeveloped countries.

Our newspapers tell us, presumably on good authority, that eventually photography taken from reconnaissance satellites will provide clarity of detail, expressed in terms of "ground resolution,"* nearly as good as that now obtainable with conventional aerial photographs. If photography of this quality can be obtained for civil use, somewhat as a by-product, from a satellite sent into orbit primarily for military reconnaissance, a quicker and more economical means of obtaining information than is presently available may come into being.

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*Ground resolution is the ground size equivalent of the smallest photographically resolved pattern of regularly repetitive detail, such as the bars on a resolution target.

Such high-altitude photography may not exhibit sufficient relief displacement for the measurement of object heights by stereoscopic parallax; however, for this very reason, it will provide a far more accurate photo map representation of large areas than that offered by even the most accurate photo mosaics made with conventional aerial photography, on which problems of relief displacement are very great.

Likewise, extensive use probably will be made in the future of extremely large scale photography, taken from helicopters of precisely located "sample plots," on which the agriculturist, forester, soil scientist or other photo interpreter wishes to make detailed studies. Avery (1958) is among those already pioneering the use of this kind of photography

In addition, through multiband spectral reconnaissance, use will be made of several photos taken simultaneously of the same area, from the same aircraft with a variety of photographic films and filters. Already photo interpreters have found that much more complete information about an area can be obtained when two or more such types of photography are interpreted in concert, than when only one type is available for study. (Colwell, 1961).

B. PHOTO INTERPRETERS WILL BE MUCH MORE RIGOROUSLY SELECTED AND TRAINED IN THE FUTURE THAN HERETOFORE.

The previously-mentioned studies by Sims and Hall at the Timber and Forestry Bureau in Canberra, together with the work being done by Moessner and others, provide ample evidence that such measures are needed. Future testing will recognize the fact that the photo interpreter typically must work continuously for several hours at a time, without the accuracy of his work being allowed to diminish appreciably through human fatigue. Therefore greater emphasis will be placed on testing the candidate's visual and mental acuity over a long work period, instead of relying so heavily, as at present, on his "flash" performance.

C. THE EQUIPMENT USED BY PHOTO INTERPRETERS WILL BE OF A GREATLY IMPROVED NATURE.

There will be an acceleration of efforts to perfect equipment permitting the photo interpreter to view transparencies rather than opaque prints, and full color images rather than

monochromatic ones. Rheostats for adjusting light intensity will become standard equipment, and a carefully prepared series of optical glass filters will be available for viewing various features on color transparencies.

The conventional lens-stereoscope will still be used in the field, but in the office it will be replaced by viewing devices which offer variable magnification over a large range. Furthermore, stereoscopes of the future will not require the photo interpreter to examine photography for prolonged periods with his neck bent, as at present, as this restricts the flow of blood to his brain, thereby impairing his visual and mental acuity.

The initial reporting of a photo interpreter's observations will commonly be made with the aid of sound-recording machines rather than with archaic pencil and paper; with this aid he no longer will need to look away from the photo image and thus interrupt his continuity of thought and photo study. Increased speed and accuracy of interpretation will surely result from this improvement.

D. THE TECHNIQUES USED IN INTERPRETING PHOTOGRAPHS WILL BE COMMENSURATE WITH THESE IMPROVEMENTS IN EQUIPMENT.

The specific techniques will no longer be dependent on the individual whims and bad habits of the photo interpreter. Through scientific testing of alternate techniques under carefully controlled conditions, accurate information will be available for the first time, on which to base recommendations for standardized optimum techniques.

E. THERE WILL BE A GREAT INCREASE IN THE NUMBER OF APPLICATIONS MADE OF AERIAL PHOTO INTERPRETATION.

It would be inaccurate to state that there are countless fields in which photo interpretation has not yet been applied, and in which it soon will be applied. To the contrary, it seems that one or more investigators have already dabbled with photo interpretation, for better or worse, in virtually every field wherein it might conceivably be used. In the past these attempts have often been unsuccessful primarily for two reasons: (1) the investigators have been misled by overly-enthusiastic statements from which they inferred that photo interpretation is the complete arm-chair solution to all

information-gathering problems on the face of the earth; and (2) the investigators have known too little regarding the techniques of photo interpretation, and consequently have been unable to extract from the photos a great deal of the information which more competent photo interpreters could have obtained. Because of their unwarranted high hopes and their unnecessarily dismal initial failures, these investigators have, in many instances, become so disillusioned as to abandon all further consideration of aerial photography as a useful tool;-- and have persuaded many of their colleagues to do likewise. Consequently, before the prediction made in this paragraph can come true, this disillusionment must be overcome, primarily through application, by highly competent photo interpreters, of the sound principles and techniques which this paper has attempted to describe.

The day probably never will come when a photo interpreter can merely sit in the comfort of his office and, by sheer photo interpretation, make a complete and reliable analysis of all the objects and conditions with which his study is concerned. There is no complete substitute for a careful on-the-ground study. The photo interpreter who forgets this important fact will soon suffer serious embarrassment, however good his aerial photos, however superior his visual and mental acuity, and however sophisticated his photogrammetric instruments and techniques. But with due appreciation of these limitations, and through application of the principles and techniques recently made available to him, he can place photo interpretation on a much sounder footing in the future than it has been in the past.

TO SUMMARIZE: Very significant progress has recently been made in all facets related to aerial photo interpretation. As a result, the photo interpreter can now report his findings with much greater confidence than in the early days, when he was forced to rely heavily on compensating errors and empirical good luck, as he attempted to use this relatively new tool, -- the aerial photograph.

With the additional progress that we now are on the threshold of making, and mindful of the fact that there is no complete substitute for field work, we can look forward with confidence to an ever-brightening future for aerial photographic interpretation.

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